

Search of Kaonic Nuclear States at the SuperB factory

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Abstract The search of nuclear bound states of \bar{K} in few-body nuclear systems such as K^-pp , can be extended from the nuclear medium to the vacuum, using the glue-rich $\Upsilon(1S)$ decays at B-factories. Here the possibility for such a measurement at the future SuperB factory is discussed.

Keywords Few Body systems · Fragmentation into hadrons · heavy quarkonia · Kaon nuclear state

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1 Introduction

The existence of \bar{K} -nuclear bound states, such as K^-pp , K^-ppn and K^-ppnn has been predicted by Akaishi and Yamazaki [1]. They constructed a phenomenological $\bar{K} - N$ potential, using experimental data on free $\bar{K} - N$ scattering lengths and on kaonic hydrogen X-rays, with the peculiar ansatz that the $\Lambda(1405)$ resonance is a $\bar{K} - N$ bound state, instead of a simple baryon with a three-quark structure. In this model the strongly attractive $\bar{K} - N$ interaction, in the isospin $I = 0$ state, may lead to tremendously condensed systems with a cluster structure and a central nucleon density as high as 1.5 fm^{-3} . In this model very narrow ($< 100 \text{ MeV}$) and deeply bound ($\sim 100 \text{ MeV}$) kaon states (DBKS) are expected.

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The debate on their existence is still open and different theoretical approaches, quite in disagreement, have been developed (see [2] for a summary of theoretical issues). The main question concerns whether the potential is shallow or deep and, then, if the decay width is narrow enough, compared to the binding energy, to allow their observation. Furthermore, since Final State Interactions (FSI) could fake a signal, positive experimental results could be attributed to such an effect.

Since DBKS are very dense systems, made of a strange particle and a few nucleons, the study of this system is related to kaon condensation [3,4] and is important to understand astrophysical objects such as the neutron stars, where the nuclear density could reach ten times the ordinary one and where strangeness degrees of freedom could play a crucial role [5]. This could lead to the formation of strange quark matter, which could be more stable than the ordinary nuclear matter. For this reason, even after some years, the study of DBKS keeps on being a hot topic in hadron physics.

The first observation of a few hints for the lightest nuclear DBKS, the K^-pp , was done by the FINUDA experiment [6] at the DAΦNE e^+e^- collider in Frascati, stopping K^- of low energy in very thin targets of p -shell nuclei. Here, a narrow peak ($\Gamma \sim 70$ MeV) has been observed in the Λp invariant mass spectrum at a mass ~ 2.26 GeV/ c^2 corresponding to a binding energy $B \sim 115$ MeV. Therefore, the Λp pairs, which exhibit a clean back-to-back topology, have been interpreted as the decay products of such a state.

New analyses of old experiments, such as OBELIX [7] at CERN with $\bar{p} - ^4\text{He}$ annihilations at rest and DISTO [8] at SATURNE with the exclusive $pp \rightarrow pK^+\Lambda$ production at $T_p = 2.85$ GeV, claim the observation of DBKS. Nevertheless, their existence has not been established yet and further measurements are planned in the near future at several facilities. Since all of them uses kaon beams interacting with nuclear targets or heavy ion collisions, where the formation of the nuclear kaonic state occurs in the nuclear medium, new experiments in different environments could help to find out signatures of the existence of such states. In particular, a search of production of DBKS in the vacuum, rather than in the medium, can be performed at B-factories, in the direct decays of the lightest bottomonium.

2 Production of baryons and deuteron in $\Upsilon(1S)$ decays

In the bottomonium spectrum below the $B\bar{B}$ threshold there are three states, the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$. The large mass of these resonances (~ 10 GeV/ c^2) is suitable to produce baryons and anti-baryons, and few-body bound systems, as well. It should be noted that the branching ratio for the strong decays of $\Upsilon(1S)$ amounts to $\sim 80\%$. These direct decays proceed via three gluons, hence the decay products are the result of their hadronization. These glue-rich decays might also produce exotic multiquark states. For the $\Upsilon(2S)$ and $\Upsilon(3S)$ resonances, direct radiative decays, both e.m. and hadronic, compete with the gluon annihilation modes; but these states can be used to produce the $\Upsilon(1S)$.

It is well known, since many years, that baryon production from $\Upsilon(1S)$ is enhanced with respect to the continuum hadronization [10]. In particular, the CLEO experiment [11] at CESR, studying the inclusive production of baryons/antibaryons in e^+e^- collisions at $\sqrt{s} \sim 10$ GeV, finds that the enhancements of per-event total particle yields for Λ hyperon, proton and antiproton are about a factor of two in the $\Upsilon(1S) \rightarrow ggg$ decays as compared to the non resonant nearby $q\bar{q}$ continuum ($e^+e^- \rightarrow q\bar{q}$). The enhancement

for Λ production is the highest one ($\sim 2, 7$). These results are not accounted for by the JETSET 7.3 fragmentation model. For the decays through $gg\gamma$ the enhancements are smaller (except for Λ 's which is a factor ~ 2) and more in agreement with JETSET expectations.

Most interesting, concerning the differences between quark/gluon-fragmentation in the $\sqrt{s} \sim 10$ GeV energy range, is the experimental evidence of bound state production, such as deuteron (d) and antideuteron (\bar{d}), in gluonic decays of $\Upsilon(1S)$ and $\Upsilon(2S)$, that was first observed by ARGUS [12] with very low statistics and, recently, by CLEO [13]. In particular, CLEO finds that the branching ratio $\mathcal{B}(\Upsilon(1S) \rightarrow \bar{d}X)$ is of the order of 3×10^{-5} . Therefore, the results show that \bar{d} production is at least three times more likely in the hadronization of $\Upsilon(nS)$ (for $n = 1, 2$) through ggg and $gg\gamma$, compared to the hadronization of $q\bar{q}$ for the continuum production, where only an upper limit of 1×10^{-5} has been evaluated from the $e^+e^- \rightarrow \bar{d}X$ cross section. Besides, an upper limit of 1×10^{-5} has been measured for the production of \bar{d} from $\Upsilon(4S)$.

CLEO also investigated how often the \bar{d} baryon number is compensated by a d or by a combination of two nucleons (n, p): the first case occurs 1% of the times. Since the theoretical description of d or \bar{d} formation is based on the statistical coalescence model [14], where a \bar{n} and \bar{p} close to each other in phase space bind together, a precise determination of such a percentage is important, because double coalescence is unlikely and a different production mechanism, such as a primary (globally) production might be involved.

It can be also interesting to note that in heavy ion collisions the formation of bound systems, such as light nuclei/anti-nuclei or hypernuclei/anti-hypernuclei, occurs through coalescence processes. For instance, the STAR [15] experiment at RHIC has measured the ratios of the yields of anti- $^3_\Lambda H$ and $^3_\Lambda H$ and of anti- 3He and 3He in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV, which amount to ~ 0.5 , favouring the coalescence hypothesis. At STAR (anti)hypernuclei are produced with similar yields of (anti)nuclei, different from what happens at lower energies. Recently, the hunt for DBKS is also started in heavy ion collision experiments [16], but their identification in the medium is a challenge.

3 Search of kaonic nuclear states at the SuperB factory

Since bound state systems, such as antideuterons, have been found in the decays of $\Upsilon(nS)$, with $n = 1, 2$, we propose to search for DBKS at the future SuperB factory [9], which will be built in the Tor Vergata University Campus in Rome. Here, large numbers of heavy leptons and heavy quark mesons will be produced using an e^+e^- asymmetric collider, operated at a c.m. energy corresponding to the rest mass of the bottomonium resonance $\Upsilon(4S)$ with a luminosity of $10^{36} \text{ cm}^{-2} \text{ s}^{-1}$, looking for new physics. Thanks to the nano-beam scheme, at LNF-INFN, an unprecedented integrated luminosity of $10 \text{ ab}^{-1}/\text{year}$ will be achieved. A magnetic spectrometer will be installed at the machine, covering a large solid angle and designed to detect and fully reconstruct both charged and neutral particles with high efficiency and energy resolution. Operating the machine at an energy below the $B\bar{B}$ threshold it will be possible to select the rest mass of $\Upsilon(nS)$ (with $n = 1, 2, 3$) in order to study the production of DBKS in the decays which proceed through the hadronization of three gluons.

The lightest nuclear DBKS, the K^-pp , can be identified through its Λp decay mode, searching for a narrow peak ($< 100 \text{ MeV}/c^2$) at a mass of about $2.25 \text{ GeV}/c^2$ in the

Λp invariant mass spectrum and measuring the $\Lambda - p$ angular correlations, which can give important hints on the nature of the event. We can rely on the high performance of the SuperB apparatus for particle ID and full topological event reconstruction for an effective identification of the DBKS.

Since there is no medium, FSI are negligible with respect to experiments using kaon beams on nuclear targets or heavy ion collisions. Moreover, we expect that the identification from the vacuum is easier and cleaner than in heavy ion collisions.

4 Conclusions

Nowadays, the study of kaonic nuclear states is a hot topic in hadron physics, because their existence is related to kaon condensation and to the physics of the core of neutron stars. Theoretical models disagree about the possibility to observe such states and only scarce experimental measurements in the nuclear medium are available. More and new experiments in different environments would be useful for a comparative analysis of the results. Search of the light K^-pp state could be extended from the nuclear medium to the vacuum, looking for its production in the strong decays of $\Upsilon(1S)$ at future B-factories, taking advantage of the high luminosity of these machines.

Measurements of the production yields of this state from the lightest bottomonium should give important clues, not only about the nature of these states, but also about the hadronization processes of quarks and gluons.

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